Title: Chemical Signatures of Ancient Activities at Chan b'i – A Submerged Maya Salt Works, Belize

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Abstract

Chemical analysis was undertaken at Chan b'i, an Early Classic (A.D. 300-600) ancient Maya submerged salt work to find activity areas not apparent from artifactual materials recovered from excavations. Chan b'i is one of 105 salt works located underwater in Paynes Creek National Park, Belize where wooden buildings are preserved due to mangrove peat matrix. The acidic peat (pH 6) preserved wood and other botanical remains, but is not conducive to the preservation of bone. Consequently, the artifactual record may be biased against the preservation of animal food remains and human burials, which are typically found at Maya settlements. In this study, we use inductively coupled plasma-mass spectroscopy (ICP-MS) to evaluate if there is evidence of other activities in addition to the salt production. The present study extends soil chemistry research to underwater archaeological sites. The results of chemical patterns indicate activity locations inside and outside of wooden architecture not shown by the artifactual remains.

Keywords

soil chemistry, ancient Maya, activity patterns, craft production, geographic information systems

1.0 Introduction

Chemical analysis of soil using inductively coupled plasma-mass spectroscopy (ICP-MS) can detect spatial variation in the concentrations of elements that allow the identification of activity areas at archaeological sites (Wells and Terry 2007). This technique seemed ideally suited to identify if salt production was the only activity undertaken at the ancient Maya Paynes Creek Salt Works (Fig. 1) or if there were additional activities, including use as residences. Since the salt works were submerged by sea-level rise after they were abandoned (McKillop et al. 2010a, 2010b), the sites are underwater, making this a case study for the use of soil chemistry for inundated terrestrial sites. The Paynes Creek Salt Works were a Classic period (A.D. 300-900) industry for salt production carried out inside wooden buildings and then transported by canoe to inland Maya cities (McKillop 1995, 2002, 2005a, 2007, 2009; McKillop et al. 2014; Robinson and McKillop 2013, 2014; Sills and McKillop 2010, 2013; Watson et al. 2013). The acidic sediment matrix of the submerged sites provided an excellent matrix for preservation of wooden buildings, but not for animal bone, shell, or human burials typically recovered from ancient Maya residences. Were bone and shell once part of the archaeological record at the Paynes Creek Salt Works, but decayed in the acidic sediment?

In this study, we used ICP-MS to find out whether additional activities occurred at the salt making sites that were not preserved in the artifactual record. Previous research (McKillop 2005a, 2007, 2009; Sills and McKillop 2010, 2013) indicates Maya workers came to the salt works from their homes that were located elsewhere. This interpretation is based on the abundance of briquetage found at the Paynes Creek Salt Works and the lack of domestic household goods such as fishing weights, spindle whorls, fish and animal bones, and limited amounts of obsidian and chert. The lack of domestic remains could be due to an issue with a lack

of preservation. Chemical analysis of local sediments can help clarify our understanding of workshop production for the Classic Maya salt works.

Fig. 1 Location map of southern Belize showing Paynes Creek National Park and sites mentioned in text. Map from McKillop 2006:30 modified by C Sills.

In this study, we carried out chemical analyses of marine sediment from the Early Classic Chan b'i site (A.D. 300-600) to evaluate if there is evidence of residential settlement and/or indications of activities at the site in addition to salt production. Chan b'i has wooden posts demarcating the outlines of wooden buildings. Excavations revealed large quantities of briquetage—pottery used to evaporate brine over fires to make salt, indicating the site was used for salt production (Sills and McKillop 2013). The lack of domestic household goods such as fishing weights, spindle whorls, fish and other animal bones, human burials, and limited amounts

of obsidian and chert—all commonly found at Maya settlements—supported the interpretation that the workers lived elsewhere. Chemical analyses reported here indicate other activities were carried out at the site, in addition to salt production. The study expands use of chemical signatures as indicators of ancient activities to underwater sites. In addition, the findings of multi-crafting at Chan b'i suggest that soil chemistry is a useful technique to identify “multi-crafting” (Hirth 2009) in ancient workshops in the Maya area and beyond.

Chemical analysis of terrestrial soils in the Maya area has been successful in identifying activities not evident in the artifactual material. At the Maya sites of Aguateca (Guatemala) and Cerén (El Salvador), high values of phosphorus were interpreted as areas for food preparation, disposal, and consumption (Parnell et al. 2002; Terry et al. 2004). High values of phosphorus obtained from plaster floors in buildings from Chunchucmil, Mexico indicate that debris was swept to the corners and edges of buildings (Hutson and Terry 2006). High values of phosphorus from the main plaza at El Coyote, Honduras (Wells 2004) and from plaster surfaces at Actuncan, Belize (LeCount et al. 2016) were interpreted as areas for the preparation and consumption of food and beverages. Increased values of phosphorus coupled with zinc concentrations are interpreted as activities associated with marketplaces (Coronel et al. 2015). Heavy metals including copper, iron, mercury, manganese, lead, and zinc were associated with pigment production activities at Cerén (Parnell et al. 2002), painted urban houses at Piedras Negras, Guatemala (Wells et al. 2000), and midden deposits from craft production at El Coyote (Wells 2004). These diverse applications of archaeological soil chemistry demonstrate the wide applicability of this method to different soil forming factors in contrasting geological environments throughout southern Mesoamerica.

Beyond the Maya area, soil chemistry has been used to detect evidence of human settlement through high concentrations of phosphates from the deposition of organic waste (Lippi 1988). Organic refuse deposits show higher phosphate values than areas where these activities do not occur (Middleton and Price 1996; Terry et al. 2004). Chemical analysis can also indicate activity areas not seen on the surface, such as refuse from meals, ash from fires, and human waste (Fulton et al. 2013; Holliday and Gartner 2007; Hutson and Terry 2006; Lippi 1988; Middleton and Price 1996; Middleton 2004; Terry et al. 2000, 2004; Wells and Moreno 2010). Chemical analyses of soil sampled in a modern Maya market where vendors sold food and crafts resulted in high concentrations of phosphorus and zinc in the soil (Dahlin et al. 2007).

Ancient Mesoamericans frequently kept the floors of their homes and workshops clean by sweeping or removing debris to disposal areas. Archaeological sites that experienced rapid abandonment, such as at Aguateca and Cerén, are the exception (Aoyama 2007; Emery and Aoyama 2007; Inomata 2001; Parnell et al. 2002; Sheets 2002). Defining activity areas that were kept clean can be difficult due to the low amounts of artifacts. However, earthen or plastered floors inside of buildings can hold chemical signatures over long periods of time allowing chemical analysis to aid with interpretation of activity areas (Wells 2010).

1.1 Salt Production Activities

Salt commonly is made from salty water using two methods: solar evaporation and by heating in pots over fires, the latter producing briquetage. Solar evaporation uses warm air and the sun to evaporate water in shallow holding pans until only salt remains. This type of production was common on the north coast of the Yucatan in ancient and modern times (Andrews 1983; Andrews and Mock 2002). The Paynes Creek salt makers evaporated brine by heating it in pots over fires to make salt. This method dominated salt production for the ancient

Maya in southern Belize (MacKinnon and Kepecs 1989; McKillop 1995, 2002) and at inland locations such as the modern day salt works of Sacapulas, Guatemala (Reina and Monaghan 1981). Both methods are documented in Mesoamerica, for modern and historic salt production as well as in the archaeological record, exhibiting variability regarding site layout and composition (Andrews 1983; Dillon et al. 1998; McKillop 2002; Nance 1992; Parsons 2001; Reina and Monaghan 1981; Williams 1999, 2004; Woodfill et al. 2015).

Ethnographic and archaeological analogs are used to elucidate the structure of activity areas at the Paynes Creek Salt Works. In order to enrich the salt content of brine, salty water was leached through salt-saturated soil, which is documented ethnographically at Sacapulas (Andrews 1983; Reina and Monaghan 1981), Coasta Chica, Mexico (Good 1995), and at Nexquipayac, Mexico (Parsons 2001). The salty soil is placed into a filtering apparatus where water is repeatedly poured over the soil. The brine percolates through the soil to collect in a container below. Woven mats, sand, and grasses are variously used to filter the salty water without the soil. The salt-enriched brine is then evaporated in pots over fires. The leached soil is removed and placed into heaps, forming mounds (Andrews 1983; Good 1995; MacKinnon and Kepecs 1989; McKillop 2002; Williams 1999, 2004).

At modern day salt works, brine, wood fuel, storage jars, and tables and chairs are stored in salt production buildings near the source of salt water or soil away from the residential sector of the community (Parsons 2001; Reina and Monaghan 1981; Williams 1999, 2004). The Paynes Creek Salt Works have been interpreted as similar to the modern ethnographic examples (McKillop 1995, 2002, 2005a, 2007; Sills and McKillop 2010, 2013). The Paynes Creek salt workers produced salt inside wooden buildings but did not reside in the salt making structures. Instead, they traveled to the salt works for production.

However, the archaeological record from the Paynes Creek Salt Works, including Chan b'i, may be biased against the preservation of remains from meals and other indicators of additional activities taking place at the salt works. Additional activities as seen at the modern salt works could be discovered through chemical testing not readily apparent from the excavated artifacts. According to Parsons (2001), the salt makers of Nexquipayac have locations to leach the soil, dispose of the leached soil, store brine, as well as processing facilities including evaporation huts. The floors of the evaporation huts are frequently swept of debris during the process of mixing and making salt. At Sacapulas, activity areas inside of the salt buildings include a place for wood storage and clay vessels. The spent charcoal from previous evaporation episodes are swept along the edges and corners of the buildings (Reina and Monaghan 1981).

1.2 Soilscape at Chan b'i

At the time of occupation, the Paynes Creek Salt Works were on dry land close to the source of salty water evaporated in pots over fires to make salt (McKillop 2009; McKillop et al. 2010a, 2010b). Sea-level rise submerged the Paynes Creek Salt Works and preserved wooden architecture in Rhizophora mangle (red mangrove) peat below the sea floor in Punta Ycacos Lagoon, a salt-water lagoon system open to the adjacent Caribbean Sea. Loss-on ignition was carried out on marine sediment samples off-site near Chan b'i (McKillop et al. 2010a, 2010b). Loss-on ignition measures the amount of organic matter in a soil or sediment sample by burning the sample at high temperatures to completely burn the organic component, leaving the inorganic component. The results of the loss-on ignition indicate the marine sediment was highly organic, consisting of approximately 60% organic matter. Microscopic identification of the organic matter revealed it was red mangrove. Overlaying the mangrove peat is a layer of loose silt.

The lagoon is supplied with salt water from the Caribbean Sea to the east and fresh water from nearby Freshwater Creek that drains from the pine savanna and the granite Maya mountains. Salinity measurements show the lagoon water is saltier than water from the open sea. The salinity of Punta Ycacos Lagoon during the dry season is around 40,000 ppm verses open sea water that averages 36,000 ppm.

Current research at the Paynes Creek Salt Works is a continuation of previous projects conducted along the coast in southern Belize (McKillop 1995, 1996, 2002, 2005b, 2006, 2007). Research at the Paynes Creek Salt Works began with the discovery and excavation of three submerged sites—Stingray Lagoon, David Westby, and Orlando’s—and one terrestrial site, Killer Bee (McKillop 1995, 2002). Attribute analysis of the briquetage from the sites revealed that the salt pots were standardized, leading to an interpretation that salt was mass produced (McKillop 2002:128-134, Tables 4.1-4.6). This interpretation offered the possibility that salt was mass-produced in the southern lowlands which contrasts with earlier views that the southern Maya lowlands were not sufficient in meeting the dietary demands of the inland, urban Maya (Andrews 1983) and that fine-grade, white salt was imported from the Yucatan for the elite (MacKinnon and Kepecs 1989). Mass-production of salt at four sites was promising, but more salt works needed to be found to make a case for significant production of salt in the southern lowlands.

In 2003 and 2004, underwater survey resulted in the discovery of 41 salt production areas, including Chan b’i, associated with wooden architecture and the discovery of an ancient Maya canoe paddle, dating from A.D. 680-880, from the site of K’ak’ Naab (McKillop 2005a). Chan b’i was systematically surveyed in 2006 as part of the “Mapping Ancient Maya Wooden Architecture on the Sea Floor Project” directed by McKillop. At this time, a full-coverage (100

percent) systematic flotation survey on Research Flotation Devices was conducted across the sites to locate and flag wooden architecture. All of the flagged wooden architecture was labeled and mapped using a Topcon GTS Total Station and downloaded into the project Geographic Information System. Spatial analysis of the wooden posts at the Paynes Creek Salt Works indicates they form rectangular structures and other ancillary constructions associated with salt making (McKillop 2005a, 2007; Sills and McKillop 2010). The buildings are similar to the shapes and sizes described by Robert Wauchope in his 1938 book titled “Modern Maya Houses”.

At Chan b'i, one conventional radiocarbon date from a wooden post is dated to 2 sigma calibrated 1510 to 1460 BP and 1430 to 1310 BP. This date places the wood used for construction within the Early Classic (A.D. 300-600) period. The systematic flotation survey at Chan b'i revealed 25 wooden hardwood posts that form a rectangular building (Fig. 2). The building measures 7.25 m by 5.75 m with room divisions. Thirty-eight palmetto palm posts (*Accelracea wightii*) form two outflaring lines (Sills and McKillop 2013). The palmetto palm post lines have been interpreted as retaining walls to either shore up land or to keep water out of the salt work (McKillop 2009; Sills and McKillop 2013).

Fig. 2 Map of Chan b'i wooden architecture with room divisions (GIS map by H McKillop). The circles represent hardwood posts and the crosses represent palmetto palm posts.

Transect excavations were carried out at Chan b'i in June, 2010, to evaluate the spatial patterning of artifacts and their relationship to wooden architecture by comparing artifact distributions inside and outside of the building. Two transects were placed across the site intersecting at right angles (Fig. 3). Each transect was divided into 1 x 1 m units. All material was excavated and water screened through ¼ inch hardware cloth. Briquetage accounts for 85% of the ceramic assemblage. Briquetage includes all the pottery used to evaporate brine over fires to make salt and is typical of the assemblage at the Paynes Creek Salt Works (McKillop 1995, 2002, 2007, 2009; Sills and McKillop 2013). There were minor amounts of water jars used to store water or brine and limited numbers of sherds from serving vessels. Charcoal was abundant.

Fig. 3 Setting up a transect excavation at Chan b'i using a compass and tape (photo by H McKillop).

The briquetage at Chan b'i is located inside and surrounding the wooden building where salt production was taking place. Broken pottery was placed in the fire to help retain heat while slowly evaporating brine to make salt (Sills and McKillop 2013). Briquetage, and other artifacts,

are absent between the wooden building and inside the lines of palmetto palm posts. There is no artifactual evidence, such as fishing weights, to suggest the Maya at Chan b'i were acquiring or processing fish or other food. By way of contrast, abundant fish and shells from nearby Wild Cane Cay (McKillop 2005b) and Frenchman's Cay (McKillop and Winemiller 2014) indicate fish and mollusks were a major part of the diet for the coastal Maya in southern Belize during the Classic period. Valdez and Mock (1991) suggest that salt was produced at New River Lagoon for salt-drying fish for inland transport. Other evidence of habitation such as bones from meals, spindle whorls, serving dishes, shell, botanical remains, and stone tools are absent from Chan b'i. The plethora of briquetage and charcoal and the scarcity of domestic artifacts indicate that salt production was the main activity carried out inside wooden buildings that were not used as residences.

2.0 Methods

Sediment samples for chemical analysis were collected along the two excavated transects at Chan b'i approximately 44 cm depth below the water surface. The samples were collected from the peat matrix at 1 m intervals along the two transects. At each location, a 2-3 cm³ sediment sample was extracted from the sea floor using a clean stainless steel knife and placed separately into sterilized Whirl-pak bags. The collection of the marine sediment was arranged along the two excavated transects in order to compare the distribution of recovered artifacts with the results of the chemical analysis. Eighteen samples were collected from Transect 1 and 22 from Transect 2. The marine sediment was exported under permit from Belize Fisheries Unit and housed in a refrigerator in the Archaeology Lab in the Department of Geography and Anthropology at Louisiana State University (LSU). The marine sediment was sampled at for loss-on ignition carried out in the Coastal Geomorphology lab, and for microscopic identification

of plants carried out in the Archaeology Lab. Samples for chemical analyses were shipped to the Laboratory for Anthropogenic Soils Research at the University of South Florida (USF).

At USF, the samples were dried in refractory porcelain crucibles in a laboratory oven at 100 °C for 2 hours to remove extant moisture. A 2.00 g portion was taken from each sample, pulverized with a Coors porcelain mortar, mixed with 10 ml of .60-molar hydrochloric acid (trace metal grade) with .16-molar nitric acid (trace metal grade) in a polyethylene scintillation vial, and shaken vigorously on an electronic shaker at 220 rpm for 30 minutes. For each sample, the solution was filtered using Whatman ashless filter paper and decanted into clean polyethylene vials. The extracts were then diluted with ultrapure deionized water (type I reagent grade 18 Megaohm*cm-1 resistance) to bring the concentrations of the elements of interest into the optimal measurement range of the instrument. We decided to use a mild acid extraction (following the procedures outlined in Lewis et al. 1993) instead of total digestion of the sample because we discovered that the peat-rich marine sediments from which the samples were collected have very high amounts of organic matter. As a result, the sample area is not naturally homogenous across the surface with regard to the distribution of chemical elements of interest (see Holliday and Gartner 2007:305). If the surface was chemically homogeneous, bulk analysis of the sample (e.g., Entwistle et al. 2007) would be appropriate since any variation in chemical concentrations could then be attributed to human activities (cf. Fisher et al. 1998). Since this was not the case for the sediments in our study, distinguishing the anthropogenic contributions to the archaeological record from the extant sediment matrix required an extraction procedure (Middleton 2004:51-53). Our approach, which follows Lewis et al. 1993, has been demonstrated experimentally to be aggressive enough to extract complexed ions from anthropogenic residues in sediments while not allowing the mineral component of the sediment to dominate the extract.

All samples were analyzed using a Perkin Elmer Elan II DRC quadrupole inductively coupled plasma-mass spectrometer (with background correction techniques facilitated by the WinLab 32 software providing detection limits close to 1 ppb for most elements; reported detection limits for the ICP-MS range from 0.1 ppt [0.1 ng/L] to 1 ppb [ug/L] for most elements) at the Center for Geochemical Analysis at the University of South Florida. For calibration, known solution standards containing the elements of interest in concentrations bracketing the expected concentrations of the sample were run during the analysis. By running several standards of different concentrations, calibration “curves” were generated equilibrating instrument response with known concentration. The unknown data were then plotted on these curves and the amount of each element of interest was calculated. The calibrated concentrations of 20 elements were determined: barium (Ba), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), phosphorus (P), strontium (Sr), zinc (Zn), titanium (Ti), chromium (Cr), cobalt (Co), yttrium (Y), uranium (U), sodium (Na), magnesium (Mg), aluminum (Al), potassium (K), calcium (Ca), manganese (Mn), and iron (Fe). The results were reported in parts per million (ppm) of the element.

3.0 Results

The 40 marine sediment samples at Chan b’i chemically analyzed from Transects 1 and 2 show quantitative and spatial variability. Errors on the standards were generally better than 5 percent for high mass elements Ba through U including the replicates. Four elements, especially Na, Mg, K, and Ca, were extremely concentrated. Undiluted concentrations were in the upper ppm, consistent with expectations for samples derived from brackish water. These samples pushed the upper limits of the instrument at 10x dilution and, as a result, exhibited poor reproducibility on duplicates. All samples were reanalyzed as 100x dilution yielding good reproducibility.

For each element, the data were analyzed for discernible fluctuations. Out of the calibrated concentrations of 20 elements, 11 elements exhibited little or no variation (e.g., Ba, Cu, Pb, Hg, Ni, Zn, Ti, Cr, Co, Y, and U). These elements include the heavy metals and rare earth elements that have low concentrations not useful for assessing activity areas. However, nine elements show variation from one to two standard deviations (P, Sr, Na, Mg, Al, K, Ca, Mn, and Fe) as shown by the boxplots in Figure 4. Summary statistics for the primary elements are presented in Table 1. The elements were examined for variations and compared to the wooden architecture and the artifact distributions from Chan b'i.

Fig. 4 Boxplots of selected elements represented in ppm concentrations. The open circles represent 1.5 spread of the interquartile range. The asterisks represent 3.0 spread of the interquartile range (P=phosphorus, Sr=strontium, Mn=manganese, Mg=magnesium, Al=aluminum, K=potassium, Fe=iron, Ca=calcium, Na=sodium).

Table 1: Summary statistics for the primary elements.

	Minimum	Maximum	Range	Mean	Median	Standard Deviation	Coefficient of Variation
Elements that exhibit little or no variation							
Ba	0.010	0.130	0.120	0.036	0.034	0.022	0.000
Cu	0.280	0.500	0.220	0.359	0.357	0.047	0.002
Pb	0.040	0.350	0.310	0.141	0.137	0.065	0.004
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.170	0.900	0.730	0.466	0.282	0.289	0.083
Zn	0.770	1.950	1.180	1.248	1.228	0.207	0.043
Ti	0.340	4.890	4.550	1.444	1.205	1.044	1.089
Cr	0.030	0.290	0.260	0.118	0.062	0.084	0.007
Co	0.010	0.080	0.070	0.041	0.038	0.018	0.000
Y	0.050	0.250	0.210	0.116	0.113	0.047	0.002
U	0.050	0.920	0.870	0.314	0.223	0.244	0.060
Elements that exhibit variation							
P	0.490	6.330	5.840	2.025	1.739	1.169	1.367
Sr	1.330	11.400	10.070	3.867	3.787	1.964	3.857
Na	665.620	3844.360	3178.740	1893.423	1764.105	815.271	664666.914
Mg	15.800	89.660	73.860	45.232	44.618	19.437	377.784
Al	-0.520	687.040	687.560	146.493	108.372	146.136	21355.656
K	67.570	209.010	141.440	135.252	132.747	40.789	1663.777
Ca	138.360	2393.180	2254.820	400.494	341.486	368.229	135592.777
Mn	0.210	3.460	3.260	1.322	1.135	0.897	0.804
Fe	37.750	297.140	259.390	136.864	117.925	62.108	3857.342

Note: Negative values indicate that the concentration is below the detection limits of the instrument, as compared to calibrated sample blanks

Additionally, certain elements exhibit a statistically significant, strong, positive, linear correlation as presented in Table 2. The elements Cu, Ni, Cr, Co, and U are elements that show little or no variations among samples. There are positive linear correlations for P, Sr, Mg, K, Ca, and Mn. These six elements yielded discernable fluctuations from the sediment samples. All of these elements can be linked to chemical signatures indicative of human activities commonly found in soils from archaeological sites.

The marine sediment samples from Chan b'i derive from the bottom of a salt-water lagoon with an organic mangrove peat seafloor overlain by silt. Loss-on ignition indicates high organic matter accounting for approximately 60% of the sediment (McKillop et al. 2010a,

2010b). The concentrations of phosphorus, strontium, and manganese at Chan b'i are relatively low (<400 ppm). However, these elements exhibit variation. Strontium and barium can result from marine organisms and limestone substrate. Freshwater drains from the pine savanna and the granite Maya mountains. Sodium and calcium can be associated with calcareous sediments from brackish and saline contexts. As expected, the salinity of the water at Chan b'i resulted in high values of sodium in the sediment. However, there are variations in the sodium and calcium concentrations. Magnesium, aluminum, potassium, and iron have constant values with discernible peaks. These elements can be linked to the mineral chemistry of marine sediment including aluminum from clays (aluminosilicates) and sands as well as broken and disintegrated pieces of pottery, potassium from water, and iron from gleyed soils.

Table 2. Linear correlations for the primary elements.

	Ba	Cu	Pb	Hg	Ni	P	Sr	Zn	Ti	Cr	Co	Y	U	Na	Mg	Al	K	Ca	Mn
Cu	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	0.01	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	-0.09	0.18	0.13		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	0.16	0.65	0.14	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P	0.41	0.05	0.15	-0.08	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sr	0.49	-0.18	0.01	-0.09	0.09	0.64	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	-0.13	0.16	0.50	0.08	0.17	0.22	-0.04	-	-	-	-	-	-	-	-	-	-	-	-
Ti	0.05	0.08	0.43	-0.01	0.07	0.44	0.21	0.48	-	-	-	-	-	-	-	-	-	-	-
Cr	0.18	0.55	0.16	0.05	0.93	0.29	0.21	0.22	0.05	-	-	-	-	-	-	-	-	-	-
Co	0.24	0.59	0.20	-0.01	0.79	0.18	0.11	0.15	0.21	0.56	-	-	-	-	-	-	-	-	-
Y	0.27	0.46	0.34	0.27	0.28	0.16	0.17	0.22	0.24	0.33	0.30	-	-	-	-	-	-	-	-
U	-0.07	-0.04	0.54	0.08	0.06	0.07	0.08	0.42	0.16	0.04	0.14	-0.04	-	-	-	-	-	-	-
Na	-0.20	-0.25	0.14	0.09	-0.12	-0.04	0.02	0.22	0.19	-0.23	0.05	-0.16	0.43	-	-	-	-	-	-
Mg	0.47	-0.13	-0.06	-0.06	0.20	0.65	0.86	0.00	0.24	0.21	0.29	0.07	0.18	0.31	-	-	-	-	-
Al	0.19	-0.06	0.22	0.08	0.08	0.49	0.29	0.28	0.42	0.18	0.03	0.05	0.15	0.18	0.37	-	-	-	-
K	-0.11	-0.22	0.22	0.06	-0.11	0.08	0.04	0.21	0.33	-0.22	0.05	-0.23	0.44	0.92	0.32	0.39	-	-	-
Ca	0.51	0.02	0.04	-0.09	0.33	0.64	0.94	-0.07	0.15	0.39	0.36	0.22	0.08	-0.04	0.82	0.23	-0.02	-	-
Mn	0.37	0.53	0.19	-0.07	0.74	0.56	0.28	0.16	0.37	0.60	0.85	0.32	0.01	-0.01	0.45	0.24	0.06	0.48	-
Fe	-0.08	0.12	0.57	0.13	0.15	0.23	0.04	0.55	0.45	0.14	0.21	0.10	0.64	0.50	0.19	0.39	0.53	0.06	0.25

Note: bold type face indicates a statistically significant, strong, positive, linear correlation.

3.1 Chemistry Associated with Wooden Architecture and Artifact Assemblage

The variation in nine elemental signatures corroborates salt-production activities associated with the wooden building and suggests additional activities were occurring at Chan b'i. The chemical signatures can be interpreted in terms of the modern Maya salt production at Sacapulas (Reina and Monaghan 1981). High values for phosphorus, strontium, magnesium, aluminum, potassium, and iron are recorded from the samples acquired within and directly surrounding the wooden building. The chemical signatures for phosphorus, strontium, and sodium were displayed using a kriged spatial map based on a linear covariance (covariogram) model using ppms of each element. Kriging is a geostatistical spatial analysis model that generates an estimated surface of unknown values based on known values (Cressie 1990; Oliver and Webster 1990). The model assumes that distance and direction are correlated so that points close together are likely to have similar values than those further apart. Kriging expresses spatial data based on a variogram which describes the similarity in values between two points (Cressie 1985; Cressie and Hawkins 1980). In the present study, a linear semivariogram was chosen to show a visual probability plot of selected elemental concentrations as they vary in space (McBratney and Webster 1986).

Peaks for phosphorus, magnesium, and potassium occur together in the central area of the building and beside the wooden posts (Fig. 5). The values may indicate areas of refuse disposal from clearing or sweeping material to the walls and/or ash from fires used in the evaporation process to make salt. The excavations yielded abundant briquetage inside and surrounding the building. The chemical signatures at Chan b'i may result from salt-production activities as reported at Sacapulas (see Reina and Monaghan 1981: Figures 30-31). At Sacapulas, a dozen or more bowls are placed over a fire on a raised soil platform in the center of the salt building for

the evaporation process. The accumulated ash and charcoal from heating salty water over a fire are swept and placed on discard piles along the interior walls of the building. These activities at Sacapulas mirror the chemical signatures of selected elements associated with the wooden building at Chan b'i.

Fig. 5 Map of Chan b'i showing the outline of wooden building including the lines of palmetto palm posts indicated by crosses. Fluctuations in phosphorus are shown using a Kriged map in ppm. The map is based on a linear covariance model.

There is a high potassium value to the west of the wooden building where dense amounts of briquetage were recovered similar to the densities inside the building. The briquetage consists of Punta Ycacos Unslipped typed jars and bowls that were attached to vessel supports called

cylinders with spacers, sockets, and bases. Spacers were placed between the vessels to separate and steady them over the fire. Sockets attached the vessels to the vessel supports and bases secured the vessel supports to the ground or firing platform (see McKillop 1995: Figure 10). The majority of recovered briquetage is defined as amorphous clay lumps that are the fragmentary pieces of jars, bowls, vessel supports, spacers, sockets, and bases. Briquetage is friable with sand temper that mixed the ashes from fires along with the sediment can account for variations in the elements of aluminum, iron, and potassium.

There is a peak in strontium and calcium outside of the wooden building, 2 m to the east, near a stand of living dwarf red mangrove (Fig. 6). Because the mangrove peat extends over 5m below the sea floor, high values for strontium and calcium are unlikely to be related to the local geological substrate. Instead strontium and calcium values correlate with anthropogenic activities at the site. High values of strontium and calcium may have resulted from calcium carbonate in mangrove oysters (Crassostrea rhizophora and Isognomum alatus) that attach themselves to red mangrove prop roots elsewhere in the lagoon, but not currently near Chan b'i. Shell middens are associated with some of the salt works elsewhere in the lagoon system, favoring an interpretation that the high values of strontium and calcium in this area may reflect a former shell midden or an area for fish processing due to the enrichment of calcium carbonate from shell and/or fish bones.

The values between the two lines of palmetto palm posts are lower for phosphorus, sodium, magnesium, aluminum, potassium, and iron and higher for strontium and calcium than the values inside and around the wooden building. The lower values for phosphorus compared to the values inside and around the building suggest that the palmetto palm post area is not a locale of salt production or habitation (Fig. 5). The area is bereft of briquetage and lower in elevation than the wooden building. The sea floor has thick silt—20 cm and greater in depth—that

overlays the red mangrove peat. However, the area is demarcated by palmetto palm posts which suggest some function associated with the wooden architecture. Correspondingly, sodium values are lower than all the other tested marine sediment samples from Chan b'i. The sodium values are less than 1,000 ppm whereas the average values elsewhere at Chan b'i average 1,800 ppm (Fig. 7).

Fig. 6 Map of Chan b'i showing the outline of wooden building including the lines of palmetto palm posts indicated by crosses. Fluctuations for strontium are shown using a Kriged map in ppm. The map is based on a linear covariance model.

Fig. 7 Map of Chan b'i showing the outline of wooden building including the lines of palmetto palm posts indicated by crosses. Fluctuations for sodium are shown using a Kriged map in ppm. The map is based on a linear covariance model.

The sediment chemistry in the area of the palmetto palm posts at Chan b'i suggests three possible interpretations. The area may have served to shore up the land from encroaching seas. Long lines of palmetto palm posts at other Paynes Creek salt works have been interpreted as land-retaining features (McKillop 2009; Sills and McKillop 2013). Alternatively, or in addition, the area may have been used to extract salty peat for enriching the salinity of brine before it was evaporated in pots over fires in the building at Chan b'i. Extraction of peat would account for the lower elevation, which would have filled up with silt. Similar types of leaching processes have

been documented throughout Mesoamerica (Andrews 1983; Good 1995; MacKinnon and Kepecs 1989; McKillop 2002; Parsons 2001; Reina and Monaghan 1981). An analogous leaching process at Chan b'i might account for the low sodium values recorded between the two lines of palmetto palm posts. The salty peat for leaching was likely excavated in close proximity to the salt works as demonstrated at the modern salt works at Nexquipayac and Sacapulas (Parsons 2001; Reina and Monaghan 1981). Perhaps the area was used to dump de-salinated soil after the leaching process. A fourth possible use of the area was for processing fish and/or shellfish, including discard of material, which could account for the high strontium and calcium values, similar to those outside the eastern end of the wooden building at Chan b'i (see Fig. 6).

4.0 Conclusion

Chemical sediment analysis ICP-MS at Chan b'i an Early Classic Maya salt work was successful in defining activity areas associated with salt making along the southern coast of Belize. The elevated elemental concentrations of phosphorus, magnesium, and potassium inside of the wooden building corroborates the hypothesis that salt production using the briquetage technique was occurring inside of the building. The comparison of the chemical signatures and their association with the wooden architecture and artifact distribution are similar to the modern salt production at Sacapulas in which the refuse from fires was swept to the corners of the building. Comparable activities of leaching salty sediment, placing the brine into a container, and evaporating the brine over fires to make salt have been documented in the historic, ethnographic, and archaeological record in the Maya area and elsewhere in Mesoamerica. Chemical signatures in the marine sediment matrix at the salt works suggest fish and shell processing as well as extraction of salty soil for leaching that were not evident from study of the associated wooden

architecture and artifact assemblage. This suggests that the salty sediment was extracted immediately adjacent to the leaching and heating areas.

Chan b'i is the first underwater Maya site where marine sediment from archaeological deposits was analyzed by acid extraction ICP-MS to prospect for anthropogenic disturbances. Our study follows a series of sites in the Maya where soil chemistry was successful in identifying the spatial patterning of activities not evident in the artifactual material alone. The finished product salt does not preserve in the archaeological record unlike the organic artifacts recovered from Chan b'i—wood, botanicals, and charcoal—and the ceramics that are well preserved in the saline and mangrove pear environment. The remarkable preservation does not extend to ash from fires or refuse such as bone from preparation and consumption activities. Soil chemistry has successfully extended our interpretation of salt activities at Chan b'i by applying a traditional terrestrial technique within archaeology to an inundated site. As sea-levels continues to rise across the world and in the Maya area this technique can contribute to the investigation of other underwater archaeological sites.

Evaluating the spatial patterning of sediment chemistry, wooden architecture and artifacts at Chan b'i with ancient, historic, and modern salt production at sites such as Sacapulas provides a fuller interpretation of activities at the salt work than by artifact analysis alone. The interpretations made from Chan b'i can be applied to the over 105 salt works discovered in Paynes Creek further expanding our knowledge on the organization of production of an important Classic period necessity.

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